PROGRESS REPORT

ON

RADIOECOLOGICAL INVESTIGATIONS AT ROCKY FLATS

TO

EG&G ROCKY FLATS, INC.
ROCKY FLATS PLANT
P.O. BOX 464
GOLDEN, COLORADO 80402-0464

AGREEMENT ASC 49074 WS

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I. INTRODUCTION AND OVERVIEW

This constitutes a report on progress to date on Contract ASC 49074 WS. This project was first funded on June 26, 1989, and work began shortly thereafter. The project has three main objectives. These are (1) to provide an updated, state-of-the-art assessment of an appropriate cleanup standard for plutonium and americium in soil east of the 903 Pad at Rocky Flats; (2) to evaluate the current distribution of plutonium, americium and other radionuclides in the terrestrial environment near the 903 Pad, and to compare the present distribution of plutonium with that measured in the early 1970s, and (3) to initiate long-term studies on terrestrial plant and animal ecology, on a Plant-wide (buffer zone) scale, at Rocky Flats. These studies are deemed important for documentation of environmental conditions as required under the National Environmental Policy Act, and for future decisions concerning environmental remediation as required under the Resource Conservation and Recovery Act and the Superfund Amendments and Reauthorization Act.

This work builds upon research conducted and experiences gained at Rocky Flats in the early 1970s by Dr. F. W. Whicker, Dr. A. W. Alldredge, and several graduate students. This new work is adding several radionuclides of interest and an updated assessment of dose by virtue of new analysis capabilities and a state-of-the-art modeling capability developed over the last 10 years. In addition to investigators Whicker and Alldredge, Dr. Shawki Ibrahim and Dr. Les Fraley, Jr. are providing guidance to several graduate students conducting work at Rocky Flats. Students involved in the project include Susan Duffy, Kathy Higley, Scott Webb, Ernest Antonio, James Jarvis, and Kate Symonds. Mette Ohlenschlaeger, a visiting scientist from Denmark, is also assisting in the work.

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It should be noted that the work has not progressed as rapidly and efficiently as originally expected. The first year's funding was broken into several modifications, each of which generated a great deal of paperwork as well as uncertainty about continued support. Periods without a budget during the year caused CSU personnel to pursue other programs and priorities at times. Another general problem was that CSU underestimated the paperwork, procedures, and safety requirements for working in the field at Rocky Flats. This aspect is gradually smoothing out with the excellent help of Mike Turner of the S. M. Stoller Corp., but a great deal of time and effort was wasted as CSU climbed the "learning curve" for accomplishing work at the Plant Site.

Despite the difficulties noted above, the work has been gaining considerable momentum, especially over the past four months. The laboratory at CSU is now generating data on radionuclide concentrations in environmental samples at a good pace. The data quality appear to be excellent, by virtue of good facilities, equipment, experience, and a rigorous quality assurance approach. The study on general ecology has focussed primarily on the dynamics of the deer population at Rocky Flats and their use of the various habitats. Animals have been trapped, marked, equipped with radio transmitters, and movements have been followed carefully since last winter. Plant uptake studies are now using the CSU greenhouse to its full capacity and data to use in a dose assessment model should be available soon. Good progress is being made on the development of a computer simulation model to estimate the long-term movement of Pu, Am and naturally-occurring radionuclides through the environment to humans. This will provide the basis for a risk assessment for radionuclides in soil at Rocky Flats.

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In general, reasonable progress has been made on the tasks originally agreed upon by EG&G Rocky Flats and CSU. One exception, however, is the general plant ecology work as originally proposed. The primary reasons for lack of progress in this area relate to (1) budget uncertainties, altered priorities, and time commitments of the investigators, and (2) the request by Rick Roberts of EG&G to prepare an environmental evaluation procedures manual. In some respects, this manual will ultimately aid in the development of needed plant ecology studies so our involvement in the manual development should eventually be very useful to this project.

We view the CSU work as applied, medium to long term research. The work is not of a nature that can provide quick answers to complex problems. The biggest payoff for the work can be expected in 2 to 3 years from now. In that time frame, sufficient data and analysis can be completed to provide environmental guidance and information that should not have to be repeated. We hope, however, that the information being generated now can be used to good advantage in the near-term also.

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II. TASK A. EVALUATION OF STANDARDS FOR PLUTONIUM AND AMERICIUM IN SOIL AT ROCKY FLATS

A. Objective

To provide the best estimate of potential dose to the public from exposure to plutonium and americium contaminated soil in the buffer zone at the Rocky Flats Plant. This estimate can be used to develop a risk-based approach to setting reasonable cleanup standards.

B. Synopsis of the Project

Plutonium and americium have been detected in the soil around the Rocky Flats Plant. The presence of these radionuclides in the plant environment is primarily attributed to the leakage of plutonium contaminated cutting oil from 55-gallon drums previously stored on the 903 Pad at the SE corner of the site. Because of the potential hazards of plutonium, the question has arisen as to the need for remediation (i.e., removal) of the contaminated soil. The purpose of this project is to provide the best possible estimate of the potential dose to the public from the presence of plutonium and other radionuclides in the environment at Rocky Flats. This objective will be accomplished by using a mathematical model (a computerized version of the PATHWAY model) to predict the range of potential exposures to the public. In order to provide the best possible estimates of potential exposure, site-specific data will be developed and used as input for the model.

The information required to run the model includes current and past data on the distribution of plutonium in the environment. The data to be collected and used in the model will include distribution of the radioisotopes as a function of soil depth, particle size distributions of the contamination,

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radionuclide concentration on and in vegetation, and resuspension factors for various soil and meteorological conditions.

Data will be collected from transects extending from the center of the 903 Pad outward and will include a reference location as well as one down gradient of the contaminated area. The transect through the contaminated area will extend to Indiana Avenue. Sampling plots are to be located along each transect, and the spacing between plots will increase as one moves toward the east.

The exact locations of the sampling sites are to be determined after the distribution of plutonium extending from the 903 Pad has been ascertained from field surveys and soil assays.

Site-specific data on plant uptake of plutonium and americium from Rocky Flats soil are also needed for the model, since this pathway becomes relatively more important as the potential for resuspension declines. A variety of greenhouse experiments with Rocky Flats soil are underway to measure this parameter.

C. Progress on Soil Measurements and Modeling

Field surveys were conducted in the SE section of the Rocky Flats Plant Buffer Zone to help select sites for more detailed environmental analysis. Penetrating radiation measurements were taken using two FIDLERs (Field Instrument for Determination of Low-Energy Radiation). The FIDLERS were set to respond to 60 and 17 keV photons, and were used to provide a general notion of the geographical distribution of ^{241}Am and ^{239}Pu in surface soil.

Seventy-five separate locations were surveyed in the americium zone and in the buffer zone for ^{241}Am and ^{239}Pu. One minute integrated counts were taken with the instruments placed immediately adjacent to each other. Background count rates for the instruments were high; they ranged from approximately 2500 cpm for

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the unit measuring ^{239}Pu to 4500 cpm for the detector set for ^{241}Am. The highest count rates detected in the field measurement effort were approximately 2.5 times background count rates. It was also noted during the measurement process that the response of the FIDLERs strongly correlated with the amount of rock in the area being measured. Consequently, it is questionable how useful these instruments will be in providing an accurate indication of plutonium and americium in soil.

At the time of the FIDLER surveys, thirty-one surface soil samples were also collected at selected locations in the buffer zone. Hand trowels were used to collect approximately 100 g samples of soil (0 - 1 cm deep) at each location; stones and vegetative matter were removed and the samples bagged for further analyses.

An area map with radiation isopleths was prepared from the FIDLER data. No major differences were observed between the isopleths generated from this study and those obtained from previous work.

The soil samples were prepared for gross alpha and gamma spectrometric analysis and are currently being analyzed. Upon completion of the soil analysis, a more complete map of ^{241}Am and ^{239}Pu distribution in surface soil in the buffer zone will be prepared. The radionuclide distribution information will be used to select locations of sampling sites for further work. These sites will be used to provide more detailed information on the movement of plutonium in the Rocky Flats Plant Environment.

Following selection of the sampling sites, additional field work will be conducted to collect surface soil, soil from the plant root zone, vegetation and litter samples. Particular emphasis will be placed on collecting thin (~ 1 mm) layers of surface soil; these data will provide more information on the vertical

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distribution of plutonium in the layers of soil most susceptible to wind and weathering action. All samples will be analyzed and the data used as input for the computer model.

Literature reviews and discussions with Rocky Flats personnel (including Gerhard Langer), will be used to collect site specific information on environmental parameters at Rocky Flats. These data will also be used in establishing expected ranges of parameters; these will be used to perform uncertainty and sensitivity analyses with the model. The uncertainty analysis will provide information on the expected range of potential doses to the public. The sensitivity analysis will provide information on which parameters have the greatest impact on dose to the public.

D. Progress on Plant Uptake Studies

In May 1990, 520 kg of Pu and Am contaminated soil was removed from Macroplot 1 and taken to CSU for plant uptake studies. Specific sampling sites on Macroplot 1 were chosen on the basis of a higher gross count rate when measured in the field with portable FIDLER detectors that were calibrated for the 17 keV and 60 keV x-rays of ^{239}Pu and ^{241}Am, respectively. Portable detectors were supplied by the Health Physics Section, Rocky Flats Plant. Soil samples were only taken to a depth of 9 cm to insure that the highest contamination levels were obtained. The samples were taken using shovels and hand trowels. All soil samples were placed in 19 L plastic lined nursery pots, double bagged, and transported to the CSU storage shed located at the Wind Energy Research Site adjacent to the Rocky Flats Plant.

The soil was transported to the CSU Foothills Campus in June 1990. It was mixed in 60 kg batches in a small electric cement mixer, returned to the nursery

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containers, and then transported to the greenhouse located in the Molecular and Radiological Biosciences building and put in 19 L pots.

The pots were randomly divided into five groups of four containers (replicates) per group. On June 15, 1990, four species (two field crop and two garden vegetables) were seeded. Species planted were wheat, barley, radish and lettuce. These species are representative of crops and vegetables found in the Rocky Flats area. After germination of the crop plants, a 1 cm layer of sand and a 1 cm layer of gravel were applied to the surface of each soil container to prevent resuspension of soil contaminants during watering.

To date, only radishes and lettuce have been harvested. These harvested samples are currently being prepared for radiochemical analysis. The wheat and barley should reach maturity by late August or early September 1990. Radiochemical analysis of all vegetation and soil will follow.

In mid-August 1990 specimens of blue grama (Boutelua gracilis) were removed from an area northeast of Fort Collins and transplanted to the remaining Macroplot 1 soil pots. This species is abundant on the Rocky Flats Plant site. These specimens will be clipped initially and then harvested again when sufficient biomass has been achieved. Radiochemical analysis of the blue grama and soil will follow.

To provide site-specific concentration ratios for native vegetation, fifteen 25 cm deep by 25 cm diameter combined soil and vegetation core specimens were removed from Macroplot 1 in late August 1990. These cores were transported to the greenhouse at CSU and will be assayed for radionuclides after sufficient new growth has developed.

III. TASK B. DISTRIBUTION AND TRANSPORT OF RADIONUCLIDES

A. Objectives

This task constitutes a resurvey of plutonium concentrations in soil, litter, vegetation, and small mammals in two study plots established in 1972. The survey will determine whether work conducted by Colorado State University during the period 1972-1976 is still relevant and applicable. Of specific interest is whether and to what extent the distribution patterns of plutonium have changed. Soil depth profile data for Pu will indicate the rate of downward transport of radionuclides and determine if changes have occurred. Plant/soil and animal/plant concentration ratios will indicate whether the Pu mobility has changed over the past 15 years. The plutonium data will also verify whether or not measurable quantities of new plutonium have been deposited in the study plots since the earlier work.

Other aspects of this task not previously studied are to measure levels and transport rates of ^{241}Am, an ingrowth product of ^{241}Pu decay. Data from washed and unwashed vegetation should provide valuable information regarding the relative contribution of dust resuspension on plant surfaces versus true plant uptake for both Pu and Am isotopes. Comparative information on ^{232}Th, ^{226}Ra and ^{238}U will indicate how the biological mobility of natural radioactivity compares to Pu and Am. Another man-made radionuclide of interest in the present study is ^{137}Cs. Soil profile data for ^{137}Cs at Rocky Flats will be compared to worldwide fallout data from offsite locations. Finally, we will correlate gross alpha and gamma survey measurements with the radiochemical analysis data to develop a sensitive but more rapid survey technique for Pu contamination.

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B. Materials and Methods

1. Collection and Preparation of Soil and Vegetation Samples

Two study plots initially established during the period 1972-1976 were relocated and sampled for soil and vegetation during the late summer of 1989. The location of these plots (Macroplot 1 and Macroplot 2) and several background sampling sites are shown in Fig. 1. Five background sampling locations were selected: Woman Creek drainage west boundary; southwestern most corner of the buffer zone; northwest part of buffer zone (this plot was previously established by CSU in 1974); Flatiron Vista Trailhead near the intersection of Colorado Highway 93 & 128 and Trailhead Greenbelt Plateau near the same intersection. A grid was superimposed over each macroplot and sampling sites were selected using a random number generator. Ten sites from Macroplot 1 and five sites from Macroplot 2 were marked with labeled wooden stakes and colored flags for sampling. These sites, or microplots, were located by measuring the distances along two axes from the origin of each macroplot using random numbers. The locations of these sites on each macroplot are shown in Figs. 2 and 3.

Vegetation, litter and soil samples were collected from each microplot using methods comparable to those used by Little et al., 1980. A steel frame (25 cm x 25 cm square) was placed on the ground near each location stake, and all standing vegetation inside the frame was clipped at ground level and placed into a paper bag. The litter, including decaying plant material on the ground was collected by hand and placed into a separate paper bag. Below ground vegetation (i.e., roots) was not collected.

A column of soil measuring 25 cm long by 5 cm wide by 21 cm deep was excavated from each microplot in 3 cm lifts, or layers. Soil samples were double bagged separately to prevent cross contamination. A diagram of the microplot cavation showing the soil layers sampled is provided in Fig. 4. In the boratory, each layer was thoroughly mixed during the sieving process. This thod differed from Little, et al. (1980) in that in Little's work each soil yer was divided into five separate subsamples to evaluate the variability of concentration in soil. They demonstrated that the variance of Pu ncentration within each soil layer was relatively high (CV range: 0.15-3.3). erefore, values obtained from the radiochemical analysis of the current work ould provide a reasonable average Pu concentration for each soil layer.

Vegetation and litter samples were weighed after rocks, clods and other n-organic debris were removed, to estimate the current biomass. Each sample s divided into two parts of the same approximate weight and plant parts. One bsample was ground on a Wiley mill to pass an 850 μm screen and the other was trasonically washed before it was ground in the same fashion.

The ultrasonic washing protocol consisted of one ten minute wash in tergent solution (~ 100 mg of Alconox detergent in 1 L of deionized water), llowed by two rinse washes in deionized water (Skinner, 1982). The washing gime was undertaken to remove surficial dust and associated radioactivity. The shed samples were oven dried at 80°C for 12 h then allowed to equilibrate with e room environment before being ground using a Wiley mill. These samples were en stored for the radiochemical analysis.

The soil samples were air dried and then sieved using an ASTM #4 sieve .75 mm opening) to remove rocks, roots and large debris. Soil clods were ushed within a pestle and mortar prior to sieving. The soil passing through e screen was placed in a 16 oz. metal can and oven dried at 80°C for 24 h to iminate varying amounts of water in each sample. Each soil sample was then chanically sieved for 30 min on an ASTM #10 sieve (2 mm opening). Fifty grams

(± 1 g) of the material passing this sieve was placed in a plastic vial for later particle size sieving and radiochemical analysis. The remainder was sealed in a 16 oz. metal can to allow the in-growth of radon progeny. This portion of the sample will be analyzed by gamma spectroscopy for ^{241}Am, ^{137}Cs, ^{226}Ra and ^{232}Th activities.

The 50 g subsamples were surveyed for gross alpha activity using a Ludlum Model No. 43-1, 10 cm diameter ZnS probe with a Ludlum Model No. 2200 timer/scaler unit. After the gross alpha survey was completed, 10 g of the soil was removed from each subsample and placed in a vial. The 10 g subsamples comprise soil particles from 0-2 mm and will be analyzed radiochemically for Pu and Am isotopes. The remaining 40 g of soil was mechanically sieved on an ASTM #325 sieve (45 μm opening) for 30 min. The fraction passing the sieve was collected and will be analyzed radiochemically. Earlier work has shown that most of the Pu in soil was associated with the 0-45 μm particle size fraction in Macroplot 1; therefore, we are limiting the soil analysis in this study to two particle size fractions; 0-45 μm and 0-2000 μm. Eight size fractions were analyzed in the earlier study. Table 1 gives a summary of vegetation, litter and soil sampling information for both macroplots.

2. Small Mammal Trapping

The study begun at Rocky Flats in 1972 (Little, 1976) was designed to elucidate the plutonium deposition and distribution patterns in a terrestrial ecosystem immediately downwind of the 903 Pad area. The study consisted of sampling soil, vegetation, litter, arthropods and small mammals and analyzing them for ^{239,240}Pu and ^{238}Pu. The results indicated that a very small proportion of the total Pu in the ecosystem was associated with small mammal tissues and that actual tissue concentrations were very low and often not detectable.

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The purpose of this study is to determine the concentrations of Pu and americium in small mammal tissues sampled from the same plots. These data will be used to compare with the results obtained by Little (1976), to determine if the concentrations in the small mammal tissues have changed significantly in the last 15 years and to determine concentration ratios between small mammal tissues, vegetation, and soil.

Work on this project began March 27, 1990, when traps in Macroplot 2 were located. The plot measured 63 x 63 m and 36 trap locations were marked with flags. Macroplot 1 was not established until May 24, 1990. Trapping in Macroplot 2 commenced with setting out and baiting 36 traps. The first samples were collected the next morning, April 15, 1990, when five specimens were obtained. Four other trapping dates were set and a total of 26 rodents were obtained from Macroplot 2. On June 7, 1990, the 36 traps were removed from Macroplot 2 and placed on Macroplot 1. Macroplot 1 has been trapped five times including May 24, 1990, when the area was measured, flagged and baited traps set out. Two samples were obtained the first night in Macroplot 1. A total of 26 specimens have been collected to date on Macroplot 1.

The small mammal specimens are currently being identified to species. They will be dissected using techniques described in Little (1976). Samples of bone, liver, muscle and hide will be radiochemically assayed for ^{238}Pu, ^{239,240}Pu and ^{241}Am. Subsamples will be archived for future analysis of ^{226}Ra, uranium isotopes, and thorium isotopes.

3. Analysis for Plutonium in Vegetation and Litter

Vegetation and litter samples were weighed into glass beakers (0.5-1 g of litter or 1-2 g of vegetation) and a known amount of ^{242}Pu tracer was added to determine the chemical yield. The samples were then dry ashed overnight at 450°C

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followed by wet ashing with concentrated nitric acid. The sample residues were leached a second time with boiling nitric acid and filtered out. The Pu was then extracted into 30% Aliquat-336 (mixed trioctyle and tridecylmethyl ammonium nitrate) in xylene from 8 M nitric acid. This method was modified from procedures developed by Ibrahim, 1980. Several other techniques, including co-precipitation and ion exchange extraction were investigated, but we concluded that solvent extraction provided greater chemical recoveries and was the easiest to adapt to a batch procedure. Whenever the analysis procedures were modified, tracer experiments were conducted to ensure reliability of Pu concentration measurements.

Following extraction, the sample was electroplated onto a platinum disk and then counted on a 300 mm^2 diameter surface barrier detector. The average resolution (FWHM) of these detectors was about 5% and the ^{242}Pu, $^{239,240}Pu$ and ^{238}Pu peaks were easily separated. The average chemical recovery determined from the ^{242}Pu tracer was about 75% (n=108) for vegetation and litter. All of the vegetation and litter samples collected in 1989 have been analyzed.

4. Analysis of Plutonium in Soil

Soil samples were weighed into a platinum crucible, spiked with ^{242}Pu tracer and then decomposed using a pyrosulfate fusion procedure similar to that outlined by Sill, 1976. The process includes treatment with hydrofluoric and nitric acids, high heat fusion, treatment with concentrated sulfuric acid, followed by coprecipitation with $BaCl_2$. The extraction, electroplating and counting procedures are similar to those developed for vegetation and litter. A limited number of soil samples have been processed at the writing of this report. We are experimenting with methods to increase both the efficiency and

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speed of plutonium analysis. Aliquots of Rocky Flats soil will be also analyzed by the CSU Soil Testing Laboratory for general soil characteristics.

5. Analytical Quality Control and Detection Limits

An internal quality control program and participation in interlaboratory comparisons were instituted to document the validity of the analytical results. Detector backgrounds are documented on a routine basis to evaluate laboratory contamination. Standards traceable to the National Institute of Standards and Technology (NIST formerly NBS) are used routinely to determine detector efficiencies, to set energy regions, and to track instrument drift. Reagent blanks are processed to detect any external contamination. One blank is analyzed with every 6-10 samples. Reagent blank data were also needed to calculate detector limits. The minimum levels of detection of plutonium from vegetation and litter is 0.05 pCi and that for soil is 0.03 pCi based on the computation outlined by Currie, 1968. A tracking plot of reagent blank values is presented in Fig. 5. The decreasing trend indicates improving control of the laboratory environment. A number of replicate analyses were performed on large samples. Since these samples are not carried through the analytical procedure together, they are not affected similarly by laboratory conditions, and hence give a good estimate of laboratory precision. The coefficient of variation (CV) of these replicate analyses was about 27% of the mean value. The variance of Pu concentrations also reflects minor changes in the analytical procedure as it evolved during research.

The internal quality control program including replicate analyses provides an estimate of the laboratory precision. The accuracy of the analytical technique will be determined by participating in interlaboratory comparisons. Our group has been previously involved in several programs and has recently

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joined one sponsored by the International Atomic Energy Agency (IAEA). Through this program, specially prepared samples are sent to the participants for analysis of radionuclides in which they have an interest. Reported values by member laboratories are published annually.

C. Results, Discussion and Comparison to Earlier Work

1. Biomass of Vegetation and Litter

The Rocky Flats area is dominated by a large number of grass and forb species. For the most part, the land has not been grazed or systematically disturbed over the years. With respect to estimates of standing crop (vegetation and litter) biomass, we present the data in Table 2. Average dry mass in g/m^2 of vegetation and litter observed from this study is generally within the range reported earlier for data collected and averaged over several years. These data will be used to calculate radionuclide inventories in the biological compartment of the Rocky Flats ecosystem. Vegetation and litter account for the vast majority of the biomass relative to other biological compartments (arthropods and mammals).

2. Plutonium Isotopes in Vegetation and Litter

The mean concentrations of $^{239,240}Pu$ and ^{238}Pu in washed and unwashed vegetation and litter for both macroplots are given in Table 3. Preliminary statistical analysis demonstrate significant skewness in the data. A summary of mean, geometric mean, and median values from Macroplot 1 is provided in Table 4. Sample size from Macroplot 2 was too small to calculate such information. Plutonium concentrations in vegetation and litter from Macroplot 2 were lower than from Macroplot 1 by over 2 orders of magnitude. Macroplot 1 is only about 100 m southeast of the 903 Pad (formerly the oil barrel storage site and the major plutonium source term), while Macroplot 2 is approximately 1 km south of

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the storage pad (Fig. 1). The mean vegetation concentration in Macroplot 1 was an order of magnitude lower than for litter. There is probably a significant fraction of Pu activity associated with surface soil that was included in both washed and unwashed litter samples.

Total plutonium concentrations ($^{239,240}Pu$ + ^{238}Pu) in vegetation from the earlier study (Little, 1976) were 29 and 0.56 pCi/g for Macroplot 1 and Macroplot 2, respectively. These values are much higher than those observed in the current work (Table 3). It is worth mentioning that in the earlier study vegetation and litter samples were cleansed of surface dust by dry sieving followed by water flotation. In this work; however, a more efficient sample cleaning was achieved by ultrasonic washing. With regard to litter, values from the earlier study were 9 to 14 times greater than reported herein. These data provide strong evidence that a decrease in the biological availability of Pu for plant uptake and accumulation is taking place over time. Continued investigation to obtain soil values and plant/soil concentration factor estimates is warranted to elucidate any changes of Pu bioavailability with time. The earlier data were more variable as seen from the coefficients of variation (CV) relative to the current work (Table 3).

Generally, ultrasonically washed vegetation and litter from both macroplots had lower plutonium concentrations than for unwashed samples. The ratio of plutonium concentrations in unwashed:washed vegetation and litter from Macroplot 1 is summarized in Table 4 and ranged from 2-3. The removal efficiency for the ultrasonic washing procedure used was estimated from Ti tracer experiments to be about 75% for a similar environment, but for a different plant type (Skinner, 1982). Therefore, residual surficial activity probably contributed somewhat to the observed values from washed vegetation and litter. Earlier work around a uranium production site concluded that contamination of plant surfaces from windblown material and rain spattering are important mechanisms of radionuclide transfer to plants in semi-arid ecosystems (Ibrahim and Whicker, 1988). This was also shown in an earlier study at Rocky Flats (Arthur and Alldredge, 1982).

The isotopic ratio of $^{239,240}Pu/^{238}Pu$ in vegetation and litter from Macroplot 1 ranged from 48 to 53 and 67 to 89, respectively, (Table 5). Most of ^{238}Pu concentrations from Macroplot 2 were below detection limits, thus the above ratio could not be calculated. Most of the plutonium analyses in the earlier study resulted from liquid scintillation counting in which no distinction between $^{239,240}Pu$ and ^{238}Pu can be made. Three vegetation and four litter samples were, however, processed for isotopic plutonium by a commercial laboratory. Based on the limited data from the earlier study, the Pu isotopic ratio appeared to be within the range observed presently (Table 5).

3. Plutonium Isotopes in Soil

A limited number of Pu measurements in soil are available to report at this time. One soil profile from each macroplot has been completed and the results are shown in Fig. 6. Preliminary observations based on the available data are:

1) Plutonium concentrations from Macroplot 1 decreased with soil depth from 131 pCi/g at the surface to 4.0 pCi/g at 21 cm depth for soil particle size < 2 mm in diameter.

2) Plutonium concentrations from Macroplot 2 also decreased with depth and were about two orders of magnitude lower than in Macroplot 1 for the same soil particle size.

4. ^{241}Am and ^{137}Cs in Soil

Americium-241 levels in and around the Rocky Flats Plant site are of interest since it is an ingrowth product of ^{241}Pu decay.

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$$^{239}Pu(n,\gamma),^{240}Pu(n,\gamma),^{241}Pu \xrightarrow[13\ years]{\beta^-} {}^{241}Am \xrightarrow[458\ years]{\alpha}$$

It requires about 70 years for ^{241}Am to reach maximum concentrations from ingrowth. Plutonium used in nuclear weapons is principally ^{239}Pu, but it will contain about 1% ^{241}Pu by mass (Poet and Martell, 1972). The ^{137}Cs levels in the plant area are also of interest since it is a fission product that could be used as evidence for any criticality accident, should it be found at levels above those from global fallout.

Soil samples collected from ten locations in Macroplot 1 and five locations in Macroplot 2 (Figs. 2 & 3) and were analyzed. Each sample was air dried, weighed, double bagged and counted prior to sieving. The gamma ray spectral data were collected with a GeLi detector and a multichannel analyzer. The photopeak count rate for ^{241}Am (60 KeV gamma ray)and for ^{137}Cs (at 662 KeV) was converted to activity concentration (pCi/g) using a set of soil standards prepared in a similar counting geometry. Soil standards were prepared by spiking pre-weighed background soil samples with known amounts of ^{241}Am and ^{137}Cs solutions. The ^{241}Am solution was standardized at our laboratory using alpha spectrometry. The efficiency of the alpha detection system was determined using a NIST traceable standard. The ^{137}Cs solution was obtained from the Environmental Monitoring Systems Laboratory of the U.S. EPA (Las Vegas, Nevada). The background soil samples were obtained from the Rocky Flats area outside the buffer zone and were counted for 1000 min on a GeLi detector to confirm the radionuclide concentrations for normal fallout.

Results of the unsieved soil measurements for ^{241}Am and ^{137}Cs from Macroplot 1 by soil depth are summarized in Table 6. Levels of these radionuclides in soil from Macroplot 2 were below the detection limits by gamma counting, and thus are not reported. Counting errors for both radionuclides were generally ± 5%. The largest potential measurement error in the present data comes from the uncertainty in duplicating counting geometry in bags. A more complete gamma measurement to include ^{241}Am, ^{137}Cs, ^{226}Ra, and ^{232}Th are planned for the same samples after sieving to various particle size fractions in sealed metal containers.

The average concentration of ^{241}Am varied with soil depth between 27 pCi/g on the surface and 0.86 pCi/g at the 21 cm depth. The data indicate that most of the ^{241}Am is still near the surface some 25 years after the initial contamination. Surface soil concentrations for ^{241}Am ranged from 20 to 41 pCi/g, which is comparable to ground measurements reported recently at two sampling locations near Macroplot 1 (EG&G, 1990). The detectability of ^{241}Am at the 21 cm soil depth indicates a slow, but definite downward movement. In one location (Microplot 2), there appears to be two ^{241}Am peaks at the 6 to 9 and 9 to 12 cm depths. This sampling location was particularly rocky and possible mechanisms are that surface contamination migrated downward by gravity and/or with water percolation. Observed sample variability may be attributed to the initial heterogeneous pattern of contamination. The concentration of ^{241}Am was strongly correlated with depth; as soil depth increased the Am concentration decreased (Fig. 7).

Plutonium concentration in soil can be inferred from the gamma measurement of ^{241}Am if the ratio of ^{239}Pu/^{241}Am is known. The radiochemical analysis for Pu in soil, now underway, will determine the above ratio to better refine the gamma measurement results. Meanwhile, published data for the Rocky Flats area indicate that this ratio is approximately 6 to 8 (Krey, et al., 1976).

Measured concentrations of ^{137}Cs were between zero and 1.5 pCi/g over all the measured samples. The ^{137}Cs data indicate that the activity is uniformly distributed horizontally and most of the activity is confined to the top soil layers (6 to 9 cm). Observed ^{137}Cs levels are consistent with worldwide fallout in the U.S. In an aerial survey of Rocky Flats conducted in 1989, the ^{137}Cs activity ranged from 0.3 to 0.6 pCi/g averaged over a soil depth of 6 cm (EG&G, 1990), which is consistent with our findings. The soil profile indicates that ^{137}Cs is exponentially distributed with depth (Fig. 8).

Gross alpha measurements conducted on the same samples (Table 6 and Fig. 9) also indicate a strong correlation with soil depth. There was a positive correlation ($r^2 = 0.85$) between gamma measurements for ^{241}Am and gross alpha measurements (Fig. 10). These values will also be correlated with plutonium concentrations obtained via radiochemical analysis to develop a field survey technique for Pu concentration.

D. References

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IV. Task D. PLANT AND ANIMAL ECOLOGY: DEER ECOLOGY

A. Introduction

This report summarizes progress made through August 1990, on deer research at Rocky Flats. This task originally was intended to cover a broad range of studies in plant and animal ecology. However, as explained in Section I of this report, only the deer ecology work has been initiated to date. In May 1990 a separate proposal was submitted to EG&G Rocky Flats to cover future deer ecology work. As soon as the budget for this work is in place, the "Deer Ecology" project will be assigned to the Department of Fishery and Wildlife Biology with A. William Alldredge as principal investigator. In January, Ms. Kate Symonds joined the project as a graduate research assistant. Under the supervision of A. W. Alldredge, she will be conducting fieldwork on deer ecology in partial fulfillment of the requirements for a Master of Science degree in Fishery and Wildlife Biology.

B. Accomplishments

1. Telemetry Studies

An initial objective of our work is to assess habitat-use patterns of resident mule deer at Rocky Flats. Radio-telemetry was the tool selected for this task, because this methodology allows for continuous monitoring, and barring no malfunctions of transmitters, deer can be relocated at almost any time and place. Approval for use of telemetry, purchase of equipment and receipt of necessary permits were accomplished during Fall 1989.

During January-February 1990, we trapped 67 deer and fitted 25 adult females with frequency-specific transmitters attached to neck bands. Fawns and adult males were marked with numbered, yellow eartags only. Data for our trapping and marking operations are summarized in Tables 7 and 8. Fawns were not

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selected for the initial study because we speculate that they may disperse from Rocky Flats environs and establish residency elsewhere. Fawn survival and dispersal will be the focus of continued research at Rocky Flats. Because of major changes in neck size with the onset of rut, adult males were not fitted with collars. Adult females show habitat fidelity and will provide adequate data on habitat-use patterns in the buffer zone at Rocky Flats. For a major portion of their first year of life, fawns remain with their mothers, thus habitat use by adult females should reflect fawn habitat use. Males quite likely use habitats differently than females, and we hope to assess this in the future with a different telemetry configuration. The Colorado Division of Wildlife has expressed interest in working with us on this endeavor.

From February through May, we conducted relocations of all telemetered deer on a weekly basis. Beginning in June and extending through August, we made relocations approximately three times each week. This schedule was employed because we were unable to gain approval for construction of our proposed tower relocation system. Tentative approval for this system was granted verbally in late August.

Two telemetered does were found dead within two weeks after their capture. The cause of mortality was most likely coyote or feral dog kills, although stress from trapping may have influenced mortality. We observed a large feral dog chasing deer near the dump on the north side of the Rocky Flats Plant in late February. Several days later we found a telemetered doe dead in this same area. At least ten different coyotes have been observed during our surveys at Rocky Flats, and on two occasions coyotes were observed in pursuit of deer. In late May 1990, a third telemetered doe was found dead on private property about 1 km west of Rocky Flats. The cause of death for this deer is unknown.

a. Summer Habitat Use by Deer

From 31 May to 22 August, telemetered deer at Rocky Flats were relocated on 30 different days. With few exceptions all telemetered deer were relocated, and their locations were generally accurate to an area of less than 0.25 km^2. We were often able to obtain visual observations of telemetered deer, and their locations were plotted on USGS topographic maps with no error ellipse calculated. Estimated locations of deer were recorded with an estimated error elipse.

Throughout the summer, telemetered does were usually found alone or with their fawns. All marked does had at least one fawn, and most does were observed with two fawns. Very little movement was evident in 16 of 22 does, and their ranges appeared to be restricted to one or two drainages. Our relocations for six does indicated that they moved considerably. Three of these does primarily occupied the north buffer zone, crossed the east and west access roads, and occupied the south buffer zone for short periods. The remaining three does moved out of the buffer zone and across the highway. One doe spent about six weeks south of Highway 72 on a ridge north of Barbara Gulch. She then returned to the buffer zone in early August. Another doe that utilized habitats along Walnut Creek was found several times across Indiana Avenue near Great Western Reservoir. One doe spent the summer approximately five miles east of Rocky Flats at 112th Avenue and Pierce Street in a wheat field surrounded by suburbia. When the wheat was harvested in early August, she and her two fawns moved about two miles west to an area behind the Ball Corporation offices, where they remained through the end of August.

Our telemetered white-tailed doe was most frequently relocated either along lower Smart Ditch near the southeast boundary of Rocky Flats, or in the fields south of the buffer zone west of Indiana Avenue.

Generally, we found telemetered deer along drainages. The highest concentrations were typically in Woman Creek, or in the shrub-filled draws of upper Rock Creek. We occasionally observed bucks by themselves or with other bucks. The segregation of males is typical for almost all species of deer, and the unique habitat at Rocky Flats affords ample opportunity to test hypotheses regarding reasons for this segregation. From June through August we recorded no mortality in the telemetered deer population.

b. Development of a Telemetry Relocation System

During March and April, we spent considerable time planning our field telemetry system. It is essential that we establish a system which will provide maximum accuracy in our relocations of deer using the Rocky Flats buffer zone. We have evaluated the potential of our relocation system using both map and field reconnaissance. At this time we propose to construct six permanent receiving towers. Relocations will be made on a 24 hour basis throughout the year. We have designed our system to give the best accuracy for relocations on contaminated areas (SWMU's) and buffer zone property east to Indiana Avenue. We will monitor the remainder of the buffer zone with less accurate relocations, using a mobile system.

During summer we built sheds, towers and antennas for six receiving systems. We also selected sites for construction of these systems at Rocky Flats. Permission to construct the systems at Rocky Flats was not obtained until the end of August, 1990; thus, the entire summer sampling season was lost, and we were unable to complete the work we had proposed. We currently anticipate that on-site construction will take place during autumn 1990, and 24-hour monitoring of telemetered deer will begin during winter 1990-1991.

2. Summer Population Estimates for Deer

On July 16, 1990, we conducted an aerial survey to estimate deer numbers at Rocky Flats. Estimation of wildlife populations is not an easy task, and most procedures generate wide confidence intervals.

Our approach was to divide the Rocky Flats buffer zone into recognizable quadrats that were roughly a quarter of a square mile. Using a helicopter, we attempted to completely survey each quadrat, counting all deer present. Deer were classified by species, marked or unmarked, male or female and adults or fawns. Using the telemetered deer with their white neck bands, we knew how many marked deer were in the buffer zone at the time of the survey, and we could compare this figure to what we actually observed. This information allowed us to use a Lincoln/Peterson population estimator, and facilitated our calculation of confidence intervals. Three observers conducted the survey (Alldredge, Symonds and Castle), and Jim Bowman of Ptarmigan Helicopters piloted the helicopter. Visibility during the survey was good to excellent.
Our results are summarized in Table 9.

Our Lincoln/Peterson estimate for the size of the Rocky Flats deer population on 16 July 1990 is 161 deer with a 95% confidence interval of ± 35 deer, or 126-196 deer. The fawn\doe ratio is not too meaningful at this time, because many fawns remained hidden and were not observed during the survey. Barring unexpectedly high predation, the fawn\doe ratio should increase as fawns age and become more visible.

During our survey we observed only one white-tailed deer, and three deer with the yellow eartags which were affixed during trapping. These observations suggest that white-tailed deer numbers are low, relative to mule deer. Additionally, yellow eartags may not have been highly visible from the air, or perhaps the bucks and fawns that were tagged in winter 1990 have moved to other, offsite habitats.

We proposed to conduct helicopter surveys to estimate deer population numbers during the winter, 1989-90. Approval to survey the buffer zones, however, could not be obtained in time for these surveys to be conducted. We now plan to conduct a survey during January or February 1991 to obtain a winter population estimate for deer at Rocky Flats. The timing of this survey is critical and we hope to obtain expeditious approval.

3. Collection of Deer Tissue for Radionuclide Analysis

Since January, we have collected tissues from seven deer that have been killed at Rocky Flats. These deer were killed by motor vehicles in or near the Rocky Flats Plant boundary. Tissues collected were: metacarpal, liver, and muscle. Reproductive data for a single doe was collected, and teeth have been collected from all fatalities for use in aging. Deer samples will be analyzed by Dr. Whicker's laboratory in the Department of Radiology and Radiation Biology.

C. Future Work

As soon as budgets are in place, the deer ecology work at Rocky Flats will be a separate project conducted by A. W. Alldredge and students in the Department of Fishery and Wildlife Biology at Colorado State University. The following narrative describes tasks proposed in that work.

1. Habitat Use Patterns, Population Size and Radionuclide Uptake

Under this task we will build on the ongoing efforts to elucidate habitat-use patterns by mule deer in the buffer zone at Rocky Flats. Data we collect will be invaluable in making management decisions regarding remedial actions for SWMU's (Solid Waste Management Units) and in assessing impacts of future habitat alterations on the Plant's resident deer population. We will also use these data to determine the amount of time deer spend in various contaminated sites. Our data will be used, in conjunction with data from the "Radioecological Investigations" project, to assess the uptake of radionuclides by deer using contaminated areas. These data may also suggest that potential uptake of other, non-radioactive, contaminants be evaluated.

To accomplish this task it will be necessary to do the following:

(1) Establish a telemetry relocation system that can be used to monitor deer habitat use and activity patterns on a 24-hour sampling scheme throughout the year. This system will include at least six permanent receiving towers and one mobile unit. Fixed towers will be located in such a manner as to yield the most accurate data for the contaminated areas (SWMU's) and environs east of the Rocky Flats Plant. The remainder of the buffer zone will be monitored with less accuracy and will require more frequent observations with the mobile unit.

(2) Assess the accuracy of the telemetry relocation system using both field data and computer simulations.

(3) Monitor deer habitat use patterns on a 24-hour sampling scheme throughout the year, using the established telemetry relocation system. Monitoring will require the services of three people during relocation sampling periods. Monitoring will be conducted using fixed towers and a mobile unit that will make relocations throughout the buffer zone. These data will be summarized in maps that can be overlaid on vegetation maps, maps of contaminated sites and other land use maps.

(4) Determine locations of deer that move from the Rocky Flats environs, using a fixed-wing aircraft four times a year. These relocations will be necessary to determine what habitats deer use when they are not at Rocky Flats. Information from these relocations will be used to assess the potential for a hunter to harvest a deer that might be contaminated with materials from Rocky Flats. A fixed wing aircraft affords the least expensive method for relocating animals that have moved beyond the range of our permanent relocation system.

(5) Conduct population estimates for deer using the Rocky Flats Buffer Zone during summer and winter, using a helicopter. This work will involve a complete survey of the buffer zone with corrections made for deer not observed. Correction factors will come from knowing how many telemetered deer were observed during a flight and how many were actually in the buffer zone during a survey.

(6) Trap and telemeter additional adult deer to increase sample size and replace collars of animals lost from the study either because of mortality or dispersal. This activity will be necessary to maintain sample size and a random sample of deer in the buffer zone. Trapping will be accomplished using drop nets, just as we successfully used them during 1990.

(7) Assess levels for radionuclides using data for deer diets collected at Rocky Flats during the 1970's and new data for radionuclide contamination levels in vegetation and soils from the "Radioecological Investigations" project. These data, combined with other data collected under Task A and B, will be used to assess the

potential for contaminants to reach humans via ingestion of deer tissue.

(8) Collect tissues from deer that are killed on the roadways in and near Rocky Flats. Tissues from these deer will be analyzed by Dr. Whicker's lab as part of the "Radioecological Investigations" project. Data will be used to assess potential contamination pathways to humans.

2. Population Dynamics of Deer

Under this task we will build on ongoing activities, and provide data vital to assessing impacts of Plant operation on resident deer populations. These data will also be necessary in planning for remedial actions and evaluating impacts from alternative uses of the Rocky Flats Buffer Zone. Furthermore, as urbanization continues to encroach on habitats surrounding Rocky Flats, management of deer at Rocky Flats may become necessary. Our data will aid in planning for such a situation before it arises.

In almost all deer populations studied, population regulation and dispersal are associated with factors operating on the sub-adult segment of the population. In this task we propose to attach telemetry devices equipped with mortality sensors to fawns during early winter. Mortality sensors are devices in the transmitter package that increase the pulse of the transmission when the collar remains motionless for a set period of time. Use of these devices not only enables the investigator to locate animals that have died, but also, in most cases, to ascertain the cause of mortality. Fawns will be telemetered in early winter (December) because, based on previous experience, this is the period when trapping and marking is feasible and causes the least impact to fawns. Collars are designed to either expand or fall off as the fawn increases in size. Quite likely it will be sub-adult deer that disperse to environs distant from Rocky Flats and these animals could present a potential contamination pathway to humans.

To accomplish this task it will be necessary to:

(1) Purchase an additional 40 transmitters with mortality sensors and configure these devices into expandable neck collars. A sample size of 40 has been calculated to give adequate power to our statistical tests when used with a finite population correction factor.

(2) Trap and telemeter 40 fawns in the Rocky Flats Buffer Zone. Trapping will employ the drop net technique which we successfully used during 1990.

(3) Relocate all telemetered fawns at least twice weekly throughout the study period to determine mortality and causal factors.

(4) Relocate all telemetered animals that leave the buffer zone and ascertain areas where these animals reside seasonally.

D. Acknowledgements

We acknowledge Mr. Mike Turner for his prompt responses to our many and varied questions about how to work at Rocky Flats and for his understanding of what is involved in ecological research. Ms. Laura Frick has been extremely tolerant as we have learned the ins and outs of conducting research at Rocky Flats, and has been most supportive in the development of our work. Dr. G. C. White (CSU) freely gave his advice on telemetry problems, Tom Howard and Steve Steinert (Colorado Division of Wildlife) loaned us equipment and helped with deer trapping. Mr. Bill de Vergie and Mr. Chris Teter assisted in deer trapping as did numerous student volunteers from Colorado State University. Mr. Kevin Castle helped with summer telemetry relocations and construction of telemetry towers.

The cooperation and consideration of security personnel at Rocky Flats is greatly appreciated; our's is not the routine type of work they encounter.

V. Figures and Tables

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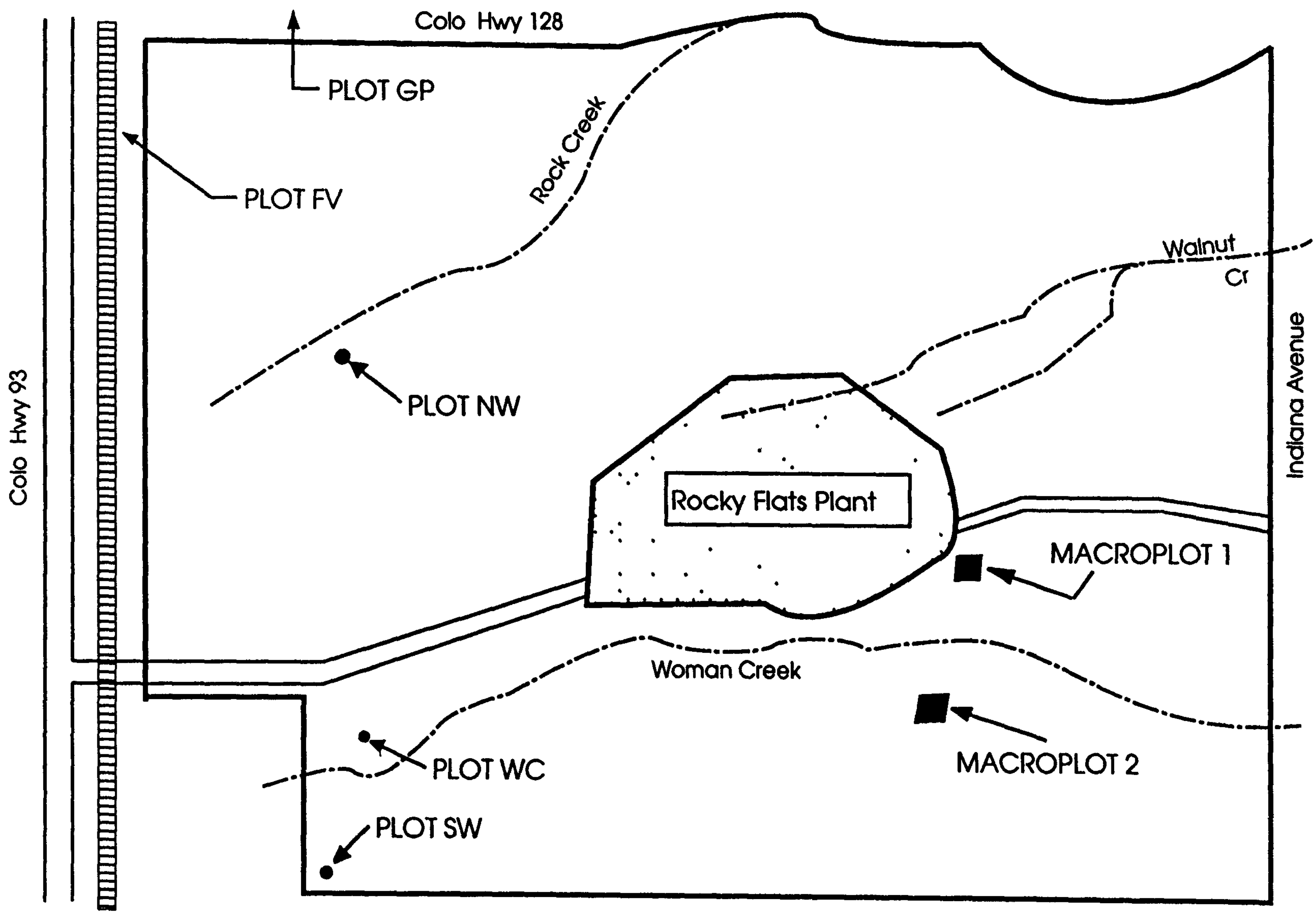

Figure 1 Map of the Rocky Flats Plant site showing CSU plots

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Figure 2. Diagram of microplot location on Macroplot 1.

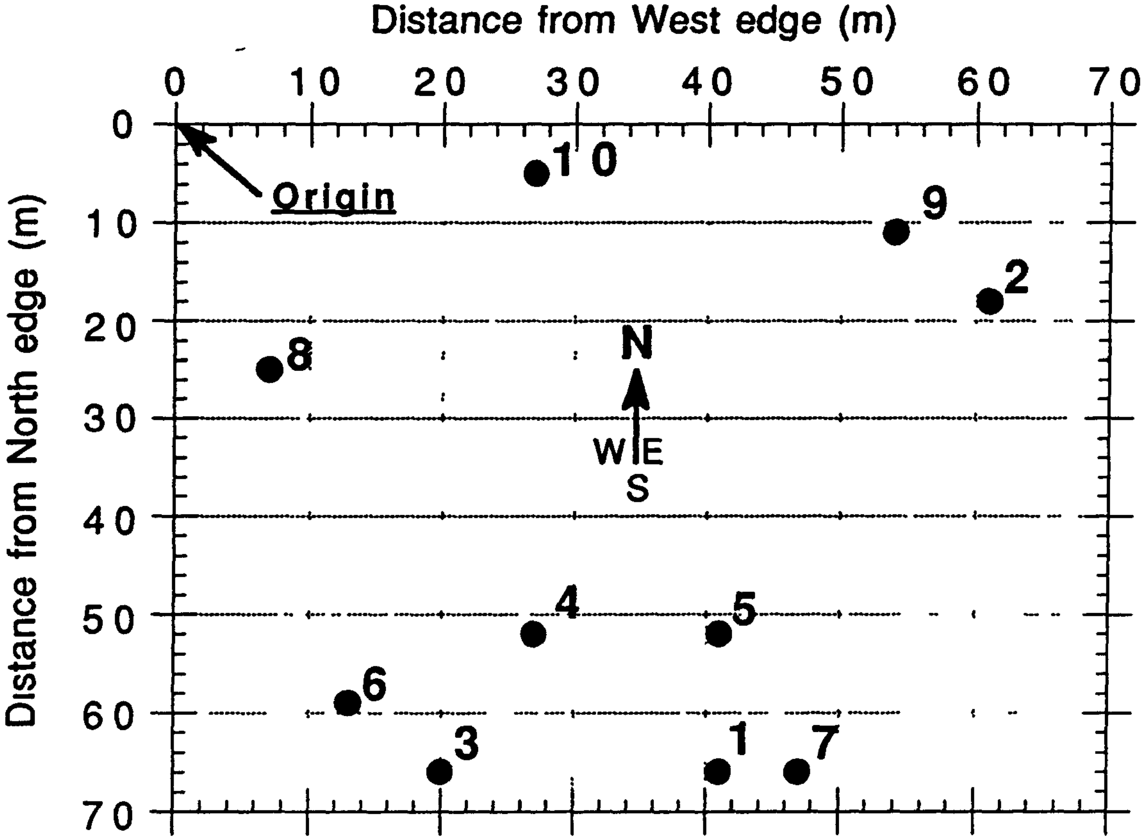

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Figure 3. Diagram of microplot locations on Macroplot 2.

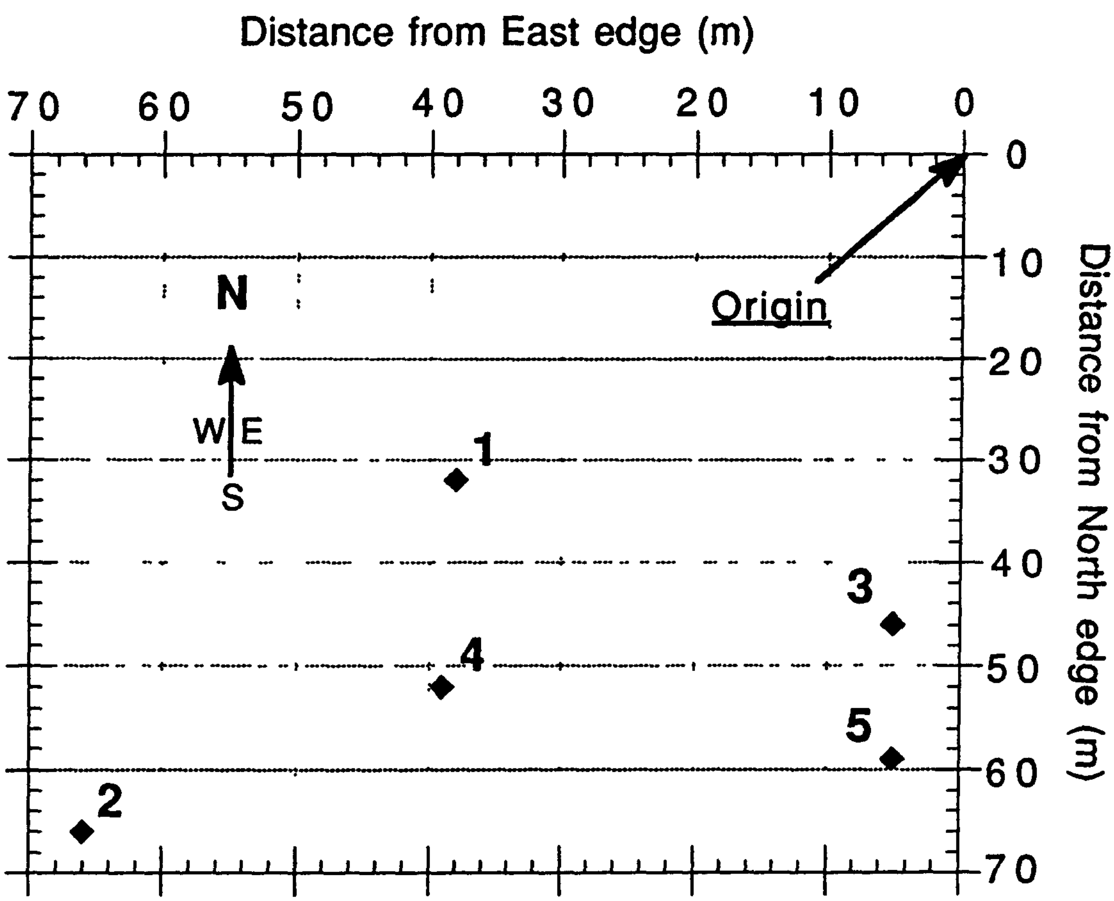

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Figure 4 Diagram of microplot excavation showing the seven layers or "benches" that were removed.

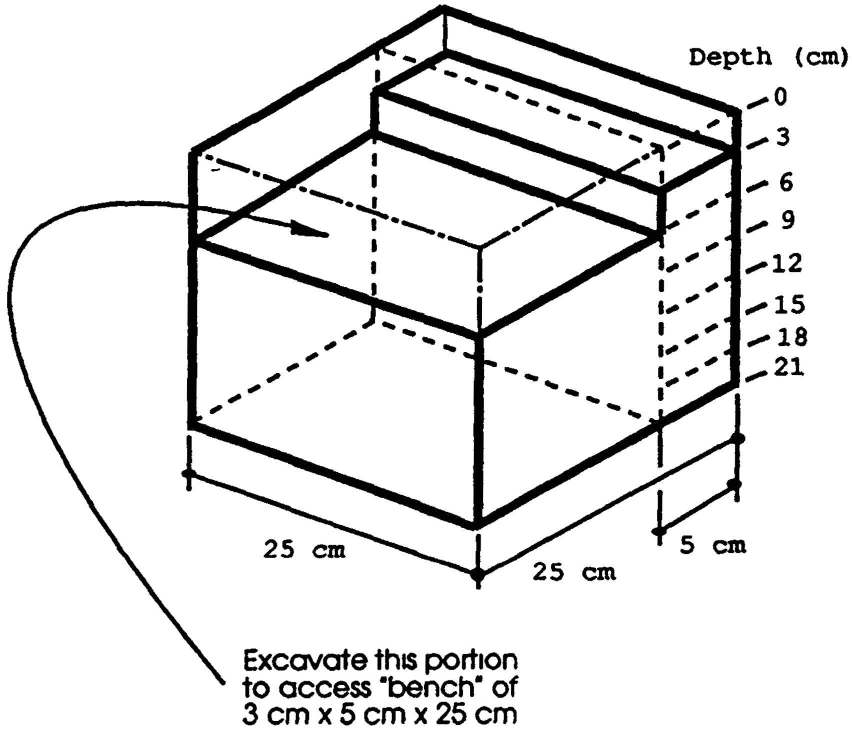

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Figure 5. Plutonium activity in acid blank samples processed during vegetation and litter analysis.

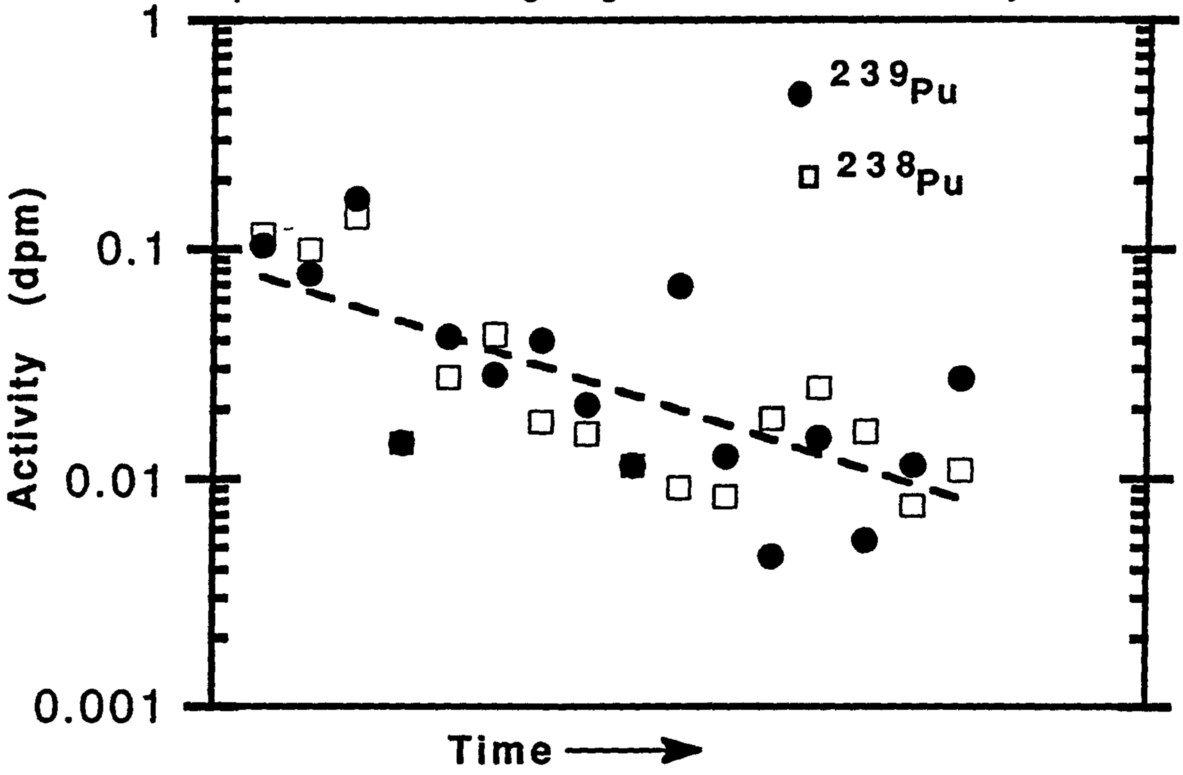

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Figure 6. Plutonium concentration in soil of particle size <2 mm

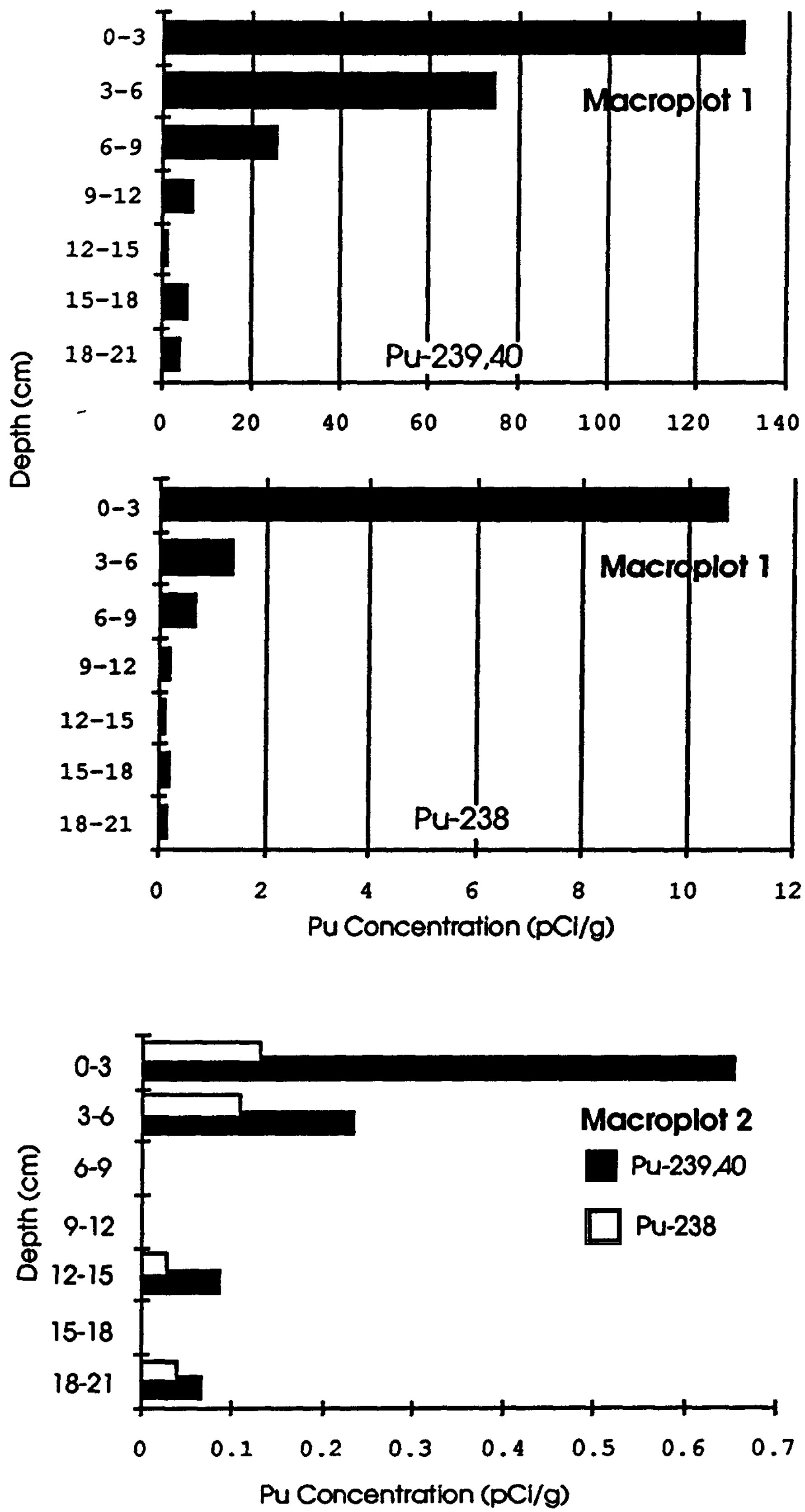

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Fig. 7. Mean ^{241}Am concentration (pCi/g) as a function of soil depth in macroplot 1.

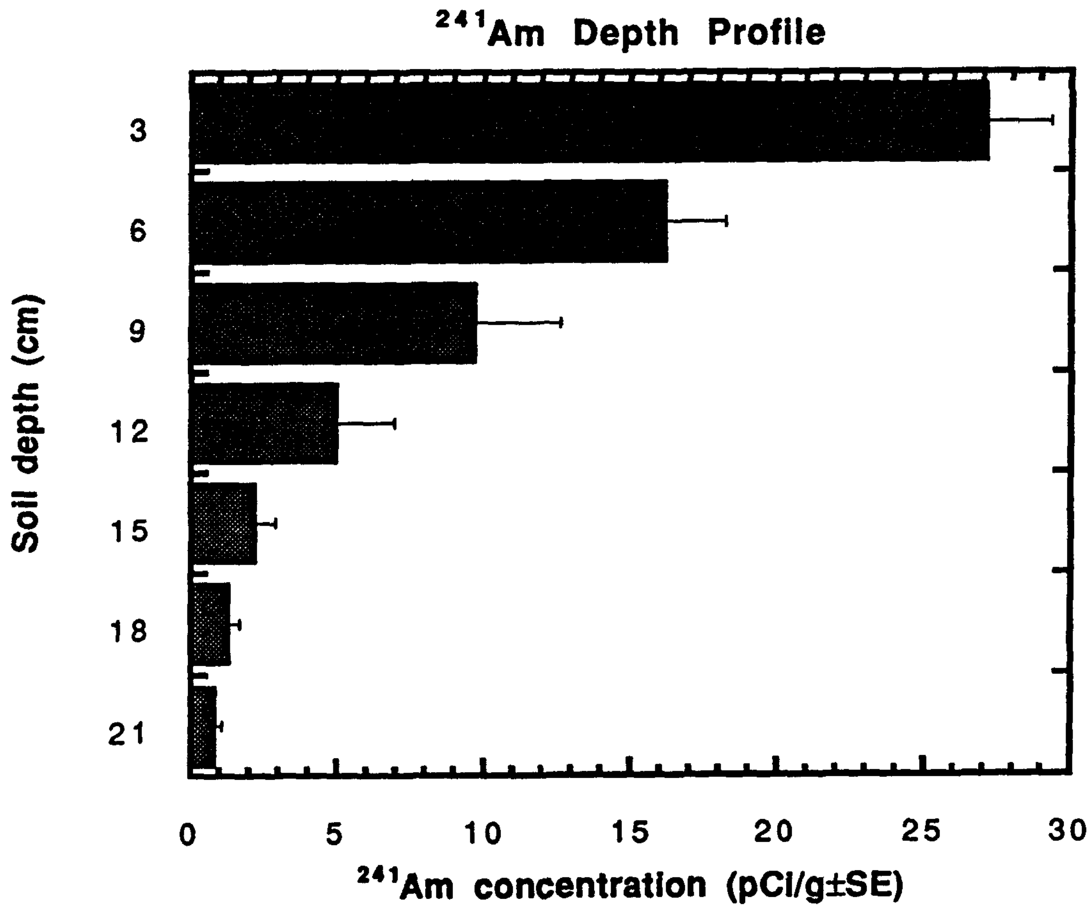

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Fig. 8. Exponential function describing ^{137}Cs concentration in soil profile from macroplot 1.

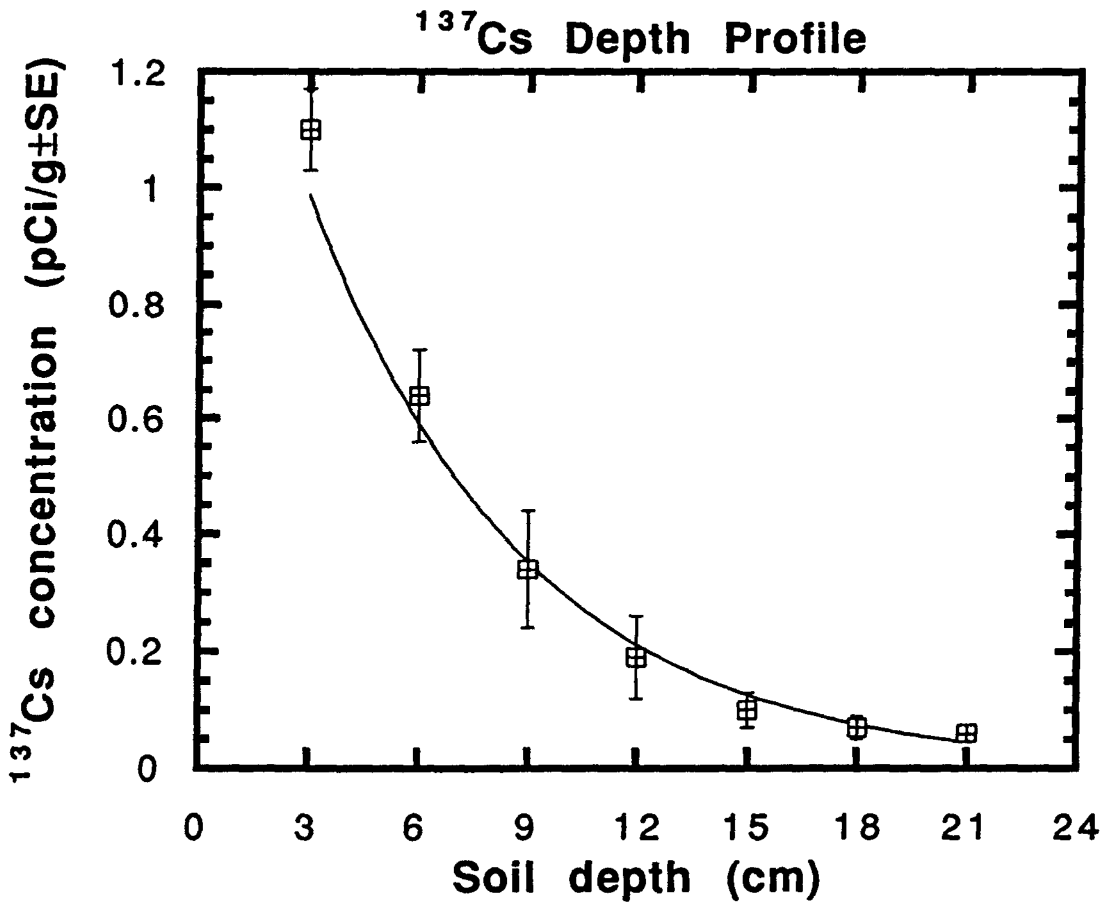

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Fig. 9. Exponential function describing gross alpha counts in soil profile from macroplot 1.

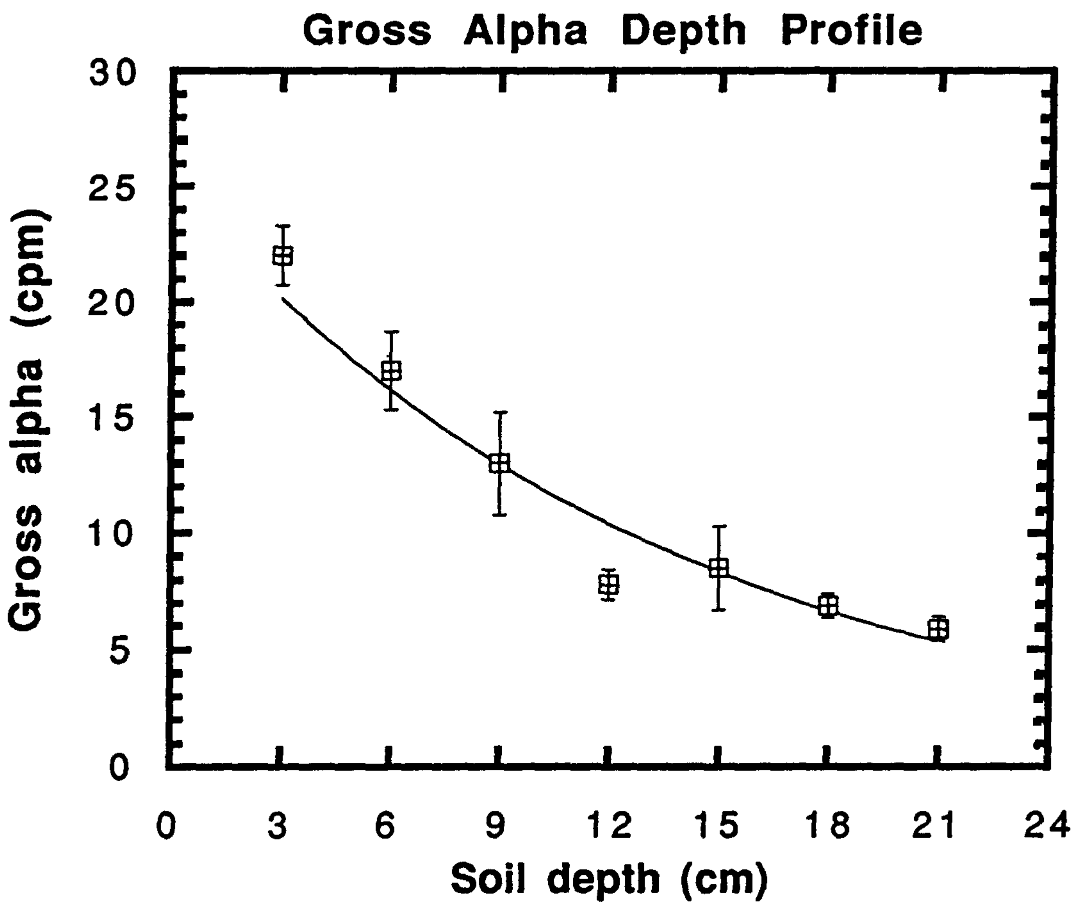

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Fig 10 Regression of gross alpha measurements versus Am-241 concentration in soil from macroplot 1

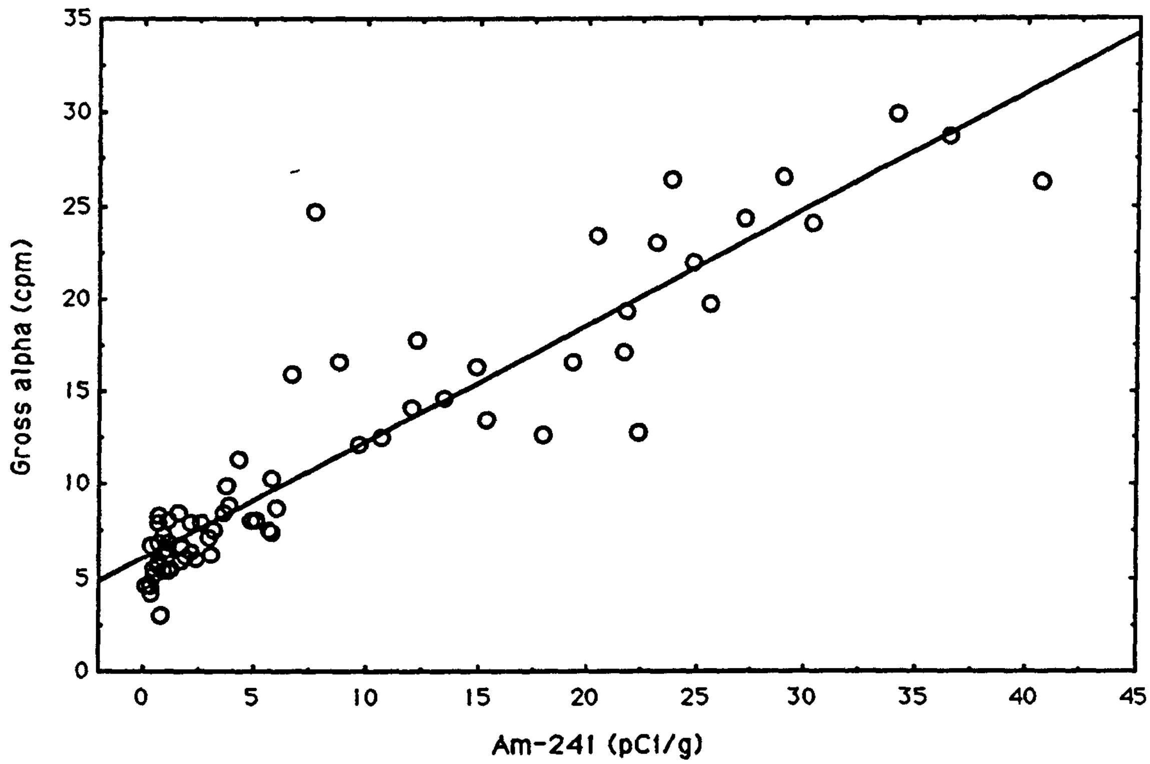

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Table 1. Sampling information at Rocky Flats.

(a) Vegetation and Litter (Samples taken September 6-26, 1990.)

Macroplot	Number of Samples: Vegetation, Unwashed	Vegetation, Washed	Litter, Unwashed	Litter, Washed
1	10	10	10	10
2	5	5	5	5
Total	15	15	15	15

Vegetation and Litter Total: 60 Samples

(b) Soil (Samples taken September 6-26, 1990.)

Macroplot	Soil Layer (cm depth)	Number of Samples: Particle Size (Sieve #), < 2 mm (#10)	< 45 μm (#325)	Total
1	1 (0-3 cm)	10	10	20
	2-7 (3-21 cm)	60 all samples	30 odd layers	90
2	1 (0-3 cm)	5	5	10
	2 (3-6 cm)	5	0	5

Soil Total: 125 Samples

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Table 2. Estimates of standing crop biomass.

Macroplot	Compartment	Mass (dry g/m^2)	
		Mean	95% CI
1 This Study	Litter	1.9×10^2	1.3×10^2 - 2.5×10^2
	Vegetation	2.8×10^2	2.3×10^2 - 3.4×10^2
1 1970's Study	Litter	4.3×10^2	3.5×10^{-2} - 5.0×10^2
	Vegetation	2.2×10^2	1.8×10^2 - 2.5×10^2
2 This Study	Litter	2.7×10^2	1.8×10^2 - 3.5×10^2
	Vegetation	3.3×10^2	2.4×10^2 - 4.1×10^2
2 1970's Study	Litter	7.9×10^2	5.4×10^2 - 1.0×10^3
	Vegetation	2.2×10^2	1.7×10^2 - 3.7×10^2

Table 3. Plutonium concentration, pCi/g, in vegetation and litter from present and earlier work.

Macroplot	Vegetation						Litter					
	$^{239,240}Pu$		^{238}Pu		Total Pu		$^{239,240}Pu$		^{238}Pu		Total Pu	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
<u>Washed Samples:</u>												
1 (this study)	2.3	0.93	0.08	1.5	2.3	0.91	17	0 50	0.26	0.63	17	0.50
1 (earlier study)	---	---	---	---	29	2.0	---	---	---	---	411	0.65
2 (this study)	0.01	0.75	-0.01	0.65	0.01	0.75	0.05	1.1	-0.01	0.15	0.05	1.0
2 (earlier study)	---	---	---	---	0.56	4.0	---	---	---	---	0.77	1.4
<u>Unwashed samples:</u>												
1 (this study)	4.4	0.88	0.10	0.94	4.5	0.87	45	0.77	0.76	0.77	46	0.77
2 (this study)	0.01	2.4	-0.01	1.2	0.01	1.8	0.15	0.64	-.01	8.8	0.15	0.61

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Table 4. Summary of central tendency values from Macroplot 1.

Sample	$^{239,240}Pu$ (pCi/g)			^{238}Pu (pCi/g)		
	Mean ± SD	Geo. Mean ± GSD	Median	Mean ± SD	Geo. Mean ± GSD	Median
Vegetation unwashed	4.4 ± 3.9	2.8 ± 3.1	3.7	0.10 ± 0.10	0.06 ± 3.2	0.07
Vegetation washed	2.3 ± 2.1	1.4 ± 3.0	1.5	0.08 ± 0.12	0.07 ± 2.9	0.03
Unwashed/Washed						
Average Ratio	2.6			2.2		
CV	0 80			4.2		
Litter Unwashed	45 ± 34	34 ± 2.2	36	0.76 ± 0 59	0.48 ± 3.4	0.64
Litter Washed	16 ± 8.2	14 ± 1.8	15	0.26 ± 0.17	0.22 ± 1.9	0.24
Unwashed/Washed						
Average Ratio	2.5			2.8		
CV	0.33			0.72		

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Table 5. Plutonium isotopic ratio in litter and vegetation from Macroplot 1.

Microplot	$^{239,240}Pu/^{238}Pu$ Isotopic Ratio			
	Vegetation		Litter	
	Unwashed	Washed	Unwashed	Washed
1	19	BDL*	271	67
2	45	BDL	45	68
3	45	73	43	64
4	59	62	50	123
5	60	29	187	68
6	50	2 5	64	61
7	22	63	47	53
8	39	58	65	47
9	112	47	60	60
10	77	BDL	55	62
Average	53	48	89	67
CV	0.51	0.51	0.87	0.31
n	10	10	10	10
Average**	---	61	---	55
CV	---	0.17	---	0.06
n	---	3	---	4

* Below detection limits

** Data from the earlier study (Little 1976).

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Table 6. Average measurement of ^{241}Am, ^{137}Cs and gross alpha from ten unseived soil samples from Macroplot 1.

Soil Depth (cm)	^{241}Am pCi/g Average ± SD	^{137}Cs pCi/g Average ± SD	Gross α cpm Average ± SD
0-3	27 ± 6.8	1.1 ± 0.22	22 ± 4.2
	(1.0 ± 0 25)[a]	(0.04 ± 0.01)	
3-6	16 ± 6.5	0.64 ± 0.27	17 ± 5.3
	(0.60 ± 0.24)	(0.02 ± 0.01)	
6-9	9.7 ± 9.2	0.34 ± 0.32	13 ± 7.1
	(0.36 ± 0.34)	(0.01 ± 0.01)	
9-12	5.0 ± 6.2	0.19 ± 0.22	7.8 ± 2.0
	(0.19 ± 0.23)	(0.01 ± 0.01)	
12-15	2.2 ± 2.1	0.10 ± 0.10	8.5 ± 5.8
	(0.08 ± 0.08)	(0.003 ± 0.003)	
15-18	1.3 ± 1.1	0.07 ± 0.06	6.9 ± 1.6
	(0.05 ± 0.04)	(0.002 ± 0.002)	
18-21	0.86 ± 0.68	0.06 ± 0.04	5.9 ± 1.7
	(0.03 ± 0.03)	(0.002 ± 0.001)	

[a]Values in Bq/g.

Table 7. Deer Trapping Results for Rocky Flats, Colorado: January through February, 1990.

Date	Species	Age	Sex	Eartag No.	Frequency	Notes
1-21	Mule Deer	Fawn	M	110	148.340	Released 3 adult males unmarked
	" "	Adult	F			
1-25	Mule Deer	Adult	F		148.320	Released 1 male fawn and 1 yearling male unmarked
	" "	Adult	F		148.330	
	" "	Adult	F		148.300	
	" "	Fawn	F	109		
	" "	Fawn	F	115		
	" "	Adult	F		148.430	
	" "	Fawn	M	101		
1-27	Mule Deer	Fawn	M	112		Released 4 males unmarked
	" "	Adult	F		148.290	
	" "	Adult	F		148.280	
	" "	Yearling	F		148.350	
	" "	Fawn	M	104		
	" "	Adult	F		148.410	
2-1	Wt. Tail	Fawn	F	100		Clover Trap
	" "	Fawn	F	102		Clover Trap
2-3	Mule Deer	Fawn	F	103		
	" "	Fawn	M	109		
	" "	Adult	F		148.300	Recapture
	" "	Fawn	M	105		
	" "	Adult	F		148.580	Old doe
	" "	Fawn	M	106		
	Wt. Tail	Yearling	M			
	Mule Deer	Adult	F		148.570	
	" "	Adult	F		148.590	
	" "	Adult	F		148.450	
	" "	Adult	F		148.460	
	" "	Adult	F		148.370	
	" "	Fawn	F	107		
	" "	Fawn	M	108		
	" "	Fawn	F	111		
	" "	Yearling	F		148.380	
	" "	Fawn	M	113		

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Table 7 (continued). Deer Trapping Results for Rocky Flats, Colorado: January through February, 1990.

Date	Species	Age	Sex	Eartag No.	Frequency	Notes
2-4	Mule Deer	Yearling	F		148.310	Clover Trap
2-6	Mule Deer	Fawn	F	114		
	" "	Fawn	M	116		
	" "	Fawn	M	117		
	" "	Fawn	F	118		
	" "	Adult	F		148.390	Dead on 2-19-90
	" "	Fawn	M	119		Released 3 adult males unmarked
2-14	Wt. Tail	Adult	F		148.420	Clover Trap
	Mule Deer	Yearling	M	120		
	" "	Yearling	M	121		
	" "	Adult	F		148.540	
	" "	Adult	F		148.550	
	" "	Adult	F		148.560	Dead on 2-17-90
	" "	Yearling	F		148.530	
						Released 2 yearling males and 1 male fawn unmarked
2-15	Mule Deer	Fawn	M	123		
	" "	Adult	M	124		Clover Trap
	" "	Adult	F		148.440	
	" "	Yearling	M	125		
2-17	Mule Deer	Adult	F		148.610	Clover Trap

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Table 8. Summary of 1990 Deer Trapping Results at Rocky Flats, Colorado.

Species	Adult Females	Adult Males	Male Fawns	Female Fawns
Mule Deer	23	16	15	9
White-tails	1	1	0	2
Total Captures: 67				

Table 9. Results of deer population estimates conducted at Rocky Flats, July 16, 1990.

Total Deer Counted	122
Total Adult Males Counted	25
Total Adult Females Counted	70
Marked	15
Unmarked	55
Total Fawns Counted	27
Male\Female Ratio	0.36
Fawn\Female Ratio	0.39

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Appendix A

Plutonium measurements in vegetation and litter

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Table A1. Plutonium concentrations in Rocky Flats vegetaion and litter. Standard deviations are in parentheses.

Microplot Number	Pu-239,40 pCi/g	Pu-239,40 mBq/g	Pu-238 pCi/g	Pu-238 mBq/g
Macroplot 1 unwashed vegetation				
1	6 6 E-1	2.4 E+1	3 5 E-2	1 3 E+0
	(7 3 E-2)	(2.7 E+0)	(2.8 E-2)	(1.0 E+0)
2	4.1 E-1	1 5 E+1	9 0 E-3	3 3 E-1
	(8.2 E-2)	(3.0 E+0)	(4.0 E-2)	(1.5 E+0)
3	1 8 E+0	6.6 E+1	4.0 E-2	1.5 E+0
	(1 5 E-1)	(5.6 E+0)	(4.5 E-2)	(1.7 E+0)
4	8.9 E+0	3 3 E+2	1 5 E-1	5.6 E+0
	(5.0 E-1)	(1.9 E+1)	(5.2 E-2)	(1.9 E+0)
5	1 2 E+1	4.6 E+2	2.1 E-1	7.7 E+0
	(1 1 E+0)	(3 9 E+1)	(4.0 E-2)	(1.5 E+0)
6	5.2 E+0	1.9 E+2	1.0 E-1	3 8 E+0
	(4.5 E-1)	(1.7 E+1)	(2.4 E-2)	(9.0 E-1)
7	6.5 E+0	2.4 E+2	3.0 E-1	1 1 E+1
	(3.7 E-1)	(1 4 E+1)	(6 7 E-2)	(2.5 E+0)
8	4.9 E+0	1 8 E+2	1.2 E-1	4.6 E+0
	(5.2 E-1)	(1.9 E+1)	(7.2 E-2)	(2.7 E+0)
9	1.5 E+0	5 5 E+1	1 3 E-2	4.9 E-1
	(2 2 E-1)	(8 0 E+0)	(5.2 E-2)	(1.9 E+0)
10	2 5 E+0	9 2 E+1	3 3 E-2	1 2 E+0
	(6 1 E-1)	(2 3 E+1)	(9 0 E-2)	(3.3 E+0)
Macroplot 1 washed vegetation				
1	5 5 E-1	2.0 E+1	-4.3 E-3	-1.6 E-1
	(4 3 E-2)	(1 6 E+0)	(1.1 E-2)	(4.2 E-1)

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Microplot Number	Pu-239,40 pCi/g	Pu-239,40 mBq/g	Pu-238 pCi/g	Pu-238 mBq/g
2	2 1 E-1	7 5 E+0	-4 5 E-3	-1.6 E-1
	(2 5 E-2)	(9 2 E-1)	(1 1 E-2)	(4 1 E-1)
3	1.6 E+0	5 9 E+1	2 2 E-2	8 1 E-1
	(8 8 E-2)	(3 3 E+0)	(1 0 E-2)	(3.8 E-1)
4	1.4 E+0	5.2 E+1	2 3 E-2	8.5 E-1
	(8.4 E-2)	(3 1 E+0)	(1.4 E-2)	(5.2 E-1)
5	5.9 E+0	2.1 E+2	2.0 E-1	7.3 E+0
	(4.6 E-1)	(1.7 E+1)	(5.6 E-2)	(2.1 E+0)
6	9.7 E-1	3.5 E+1	3.8 E-1	1.4 E+1
	(1.1 E-1)	(4.0 E+0)	(5.6 E-2)	(2.1 E+0)
7	5 5 E+0	2.0 E+2	8.7 E-2	3 2 E+0
	(4.5 E-1)	(1.7 E+1)	(2 4 E-2)	(8.9 E-1)
8	4 0 E+0	1.5 E+2	6.9 E-2	2.5 E+0
	(1.9 E-1)	(7 1 E+0)	(1.6 E-2)	(5.8 E-1)
9	2.1 E+0	7 6 E+1	4.4 E-2	1.6 E+0
	(9.8 E-2)	(3.6 E+0)	(1.0 E-2)	(3.8 E-1)
10	4.8 E-1	1.8 E+1	-1.3 E-3	-4.7 E-2
	(3.9 E-2)	(1.5 E+0)	(1.2 E-2)	(4.5 E-1)

Macroplot 1 unwashed litter

Microplot Number	Pu-239,40 pCi/g	Pu-239,40 mBq/g	Pu-238 pCi/g	Pu-238 mBq/g
1	1.5 E+1	5 4 E+2	5 4 E-2	2 0 E+0
	(2.3 E+0)	(8.4 E+1)	(8 2 E-2)	(3.0 E+0)
2	1.8 E+1	6 8 E+2	4 1 E-1	1.5 E+1
	(3.7 E+0)	(1 4 E+2)	(3.0 E-1)	(1.1 E+1)
3	2.2 E+1	8.2 E+2	5 2 E-1	1.9 E+1
	(4.4 E+0)	(1 6 E+2)	(3 2 E-1)	(1.2 E+1)
4	7.8 E+1	2.9 E+3	1.6 E+0	5.7 E+1
	(8 9 E+0)	(3 3 E+2)	(2.9 E-1)	(1.1 E+1)

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Microplot Number	Pu-239,40 pCi/g	Pu-239,40 mBq/g	Pu-238 pCi/g	Pu-238 mBq/g
5	1 2 E+1 (2 5 E+0)	4 5 E+2 (9 4 E+1)	6.6 E-2 (1 4 E-1)	2.4 E+0 (5 2 E+0)
6	4.9 E+1 (5.8 E+0)	1 8 E+3 (2 1 E+2)	7.7 E-1 (1.8 E-1)	2.8 E+1 (6.6 E+0)
7	2.2 E+1 (2.5 E+0)	8.0 E+2 (9 3 E+1)	4.7 E-1 (1.4 E-1)	1.7 E+1 (5.0 E+0)
8	1.2 E+2 (1.4 E+1)	4.4 E+3 (5.3 E+2)	1 8 E+0 (3.5 E-1)	6.7 E+1 (1 3 E+1)
9	6.6 E+1 (7.3 E+0)	2.4 E+3 (2.7 E+2)	1.1 E+0 (2.0 E-1)	4 0 E+1 (7 5 E+0)
10	4.9 E+1 (3.6 E+0)	1.8 E+3 (1 3 E+2)	9.0 E-1 (2.6 E-1)	3.3 E+1 (9.7 E+0)
Macroplot 1 Washed Litter				
1	5.2 E+0 (3 2 E-1)	1 9 E+2 (1 2 E+1)	7.7 E-2 (2.5 E-2)	2 8 E+0 (9 1 E-1)
2	7.4 E+0 (3.9 E-1)	2.7 E+2 (1.4 E+1)	1.1 E-1 (2.7 E-2)	4.0 E+0 (1.0 E+0)
3	1.5 E+1 (8.5 E-1)	5 4 E+2 (3.1 E+1)	2.3 E-1 (3.1 E-2)	8.5 E+0 (1.1 E+0)
4	2.5 E+1 (4.0 E+0)	9.1 E+2 (1 5 E+2)	2.0 E-1 (1.9 E-1)	7 4 E+0 (7 1 E+0)
5	9.1 E+0 (5 2 E-1)	3.3 E+2 (1.9 E+1)	1.3 E-1 (2.3 E-2)	4.9 E+0 (8.7 E-1)
6	2.0 E+1 (1.8 E+0)	7.2 E+2 (6.5 E+1)	3.2 E-1 (6.1 E-2)	1.2 E+1 (2.3 E+0)

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Microplot Number	Pu-239,40 pCi/g	Pu-239,40 mBq/g	Pu-238 pCi/g	Pu-238 mBq/g
7	1.4 E+1	5.2 E+2	2.7 E-1	9.9 E+0
	(8.6 E-1)	(3.2 E+1)	(4.6 E-2)	(1.7 E+0)
8	3.0 E+1	1.1 E+3	6.4 E-1	2.4 E+1
	(1.7 E+0)	(6.3 E+1)	(7.4 E-2)	(2.7 E+0)
9	2.5 E+1	9.2 E+2	4.2 E-1	1.5 E+1
	(2.1 E+0)	(7.9 E+1)	(7.3 E-2)	(2.7 E+0)
10	1.6 E+1	5.8 E+2	2.5 E-1	9.2 E+0
	(7.9 E-1)	(2.9 E+1)	(4.6 E-2)	(1.7 E+0)

Macroplot 2 Unwashed Vegetation

Microplot Number	Pu-239,40 pCi/g	Pu-239,40 mBq/g	Pu-238 pCi/g	Pu-238 mBq/g
1	-5.1 E-3	-1.9 E-1	-1.0 E-3	-3.7 E-2
	(1.3 E-2)	(4.6 E-1)	(1.2 E-2)	(4.5 E-1)
2	-3.1 E-3	-1.1 E-1	-1.2 E-3	-4.2 E-2
	(1.3 E-2)	(4.7 E-1)	(1.2 E-2)	(4.5 E-1)
3	4.0 E-2	1.5 E+0	-1.6 E-2	-5.8 E-1
	(2.1 E-2)	(7.6 E-1)	(1.5 E-2)	(5.5 E-1)
4	-4.8 E-4	-1.8 E-2	-7.2 E-4	-2.6 E-2
	(1.3 E-2)	(4.8 E-1)	(1.2 E-2)	(4.5 E-1)
5	7.4 E-3	2.7 E-1	-9.9 E-3	-3.6 E-1
	(2.0 E-2)	(7.3 E-1)	(1.6 E-2)	(6.0 E-1)

Macroplot 2 washed vegetation

Microplot Number	Pu-239,40 pCi/g	Pu-239,40 mBq/g	Pu-238 pCi/g	Pu-238 mBq/g
1	6.4 E-3	2.3 E-1	-1.1 E-4	-4.0 E-3
	(1.1 E-2)	(4.1 E-1)	(9.9 E-3)	(3.7 E-1)
2	8.8 E-3	3.2 E-1	-3.9 E-3	-1.4 E-1
	(7.0 E-3)	(2.6 E-1)	(5.6 E-3)	(2.1 E-1)

Table A1 continued.

Microplot Number	Pu-239,40 pCi/g	Pu-239,40 mBq/g	Pu-238 pCi/g	Pu-238 mBq/g
3	5.1 E-3 (7 4 E-3)	1.9 E-1 (2 7 E-1)	-5 5 E-3 (6.1 E-3)	-2.0 E-1 (2 2 E-1)
4	1.4 E-3 (6.9 E-3)	5 3 E-2 (2.5 E-1)	-5 4 E-3 (5.9 E-3)	-2.0 E-1 (2.2 E-1)
5	1.7 E-2 (8.4 E-3)	6 2 E-1 (3 1 E-1)	-8.4 E-3 (5.6 E-3)	-3 1 E-1 (2.1 E-1)
Macroplot 2 unwashed litter				
1	-8.5 E-3 (1.6 E-2)	-3.1 E-1 (6 0 E-1)	-8.9 E-3 (1.5 E-2)	-3.3 E-1 (5.5 E-1)
2	1.7 E-1 (7 8 E-2)	6 4 E+0 (2.9 E+0)	-3.9 E-3 (5.2 E-2)	-1.4 E-1 (1.9 E+0)
3	1.5 E-1 (3.5 E-2)	5.5 E+0 (1.3 E+0)	-1.2 E-2 (2.2 E-2)	-4.2 E-1 (8.0 E-1)
4	1.8 E-1 (3.1 E-2)	6 5 E+0 (1.2 E+0)	2.0 E-2 (1.4 E-2)	7.4 E-1 (5.2 E-1)
5	2.5 E-1 (3.6 E-2)	9.1 E+0 (1.3 E+0)	-3.0 E-3 (1.6 E-2)	-1.1 E-1 (6.0 E-1)
Macroplot 2 washed litter				
1	2.4 E-3 (9 5 E-3)	8.9 E-2 (3.5 E-1)	-1 2 E-2 (7.8 E-3)	-4.2 E-1 (2.9 E-1)
2	-6.8 E-3 (9 4 E-3)	-2.5 E-1 (3 5 E-1)	-8.1 E-3 (8.6 E-3)	-3.0 E-1 (3.2 E-1)
3	6 6 E-2 (1 9 E-2)	2.4 E+0 (7.2 E-1)	-1.0 E-2 (1.3 E-2)	-3.7 E-1 (4.9 E-1)

Table A1 continued.

Microplot Number	Pu-239,40 pCi/g	Pu-239,40 mBq/g	Pu-238 pCi/g	Pu-238 mBq/g
4	6 9 E-2 (1.7 E-2)	2.5 E+0 (6 2 E-1)	-1.2 E-2 (1.1 E-2)	-4 4 E-1 (3 9 E-1)
5	1.4 E-1 (2.4 E-2)	5.0 E+0 (8.8 E-1)	-1 2 E-2 (1.1 E-2)	-4 2 E-1 (4.2 E-1)

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APPENDIX B

SOIL MEASUREMENTS OF ^{241}AM, ^{137}CS AND GROSS ALPHA FROM MACROPLOT 1

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Appendix B. Soil measurements of ^{241}Am, ^{137}Cs, and gross alpha from Macroplot 1.

Soil Depth (cm)	^{241}Am pCi/g	^{137}Cs pCi/g	Gross α cpm
Microplot 1.[a]			
0.3	22	0.97	17
	(0.80)[b]	(0.04)[b]	
3-6	15	0.66	16
	(0.55)	(0.02)	
6-9	5.7	0.16	7.5
	(0.21)	(0.005)	
9-12	1.6	0.11	6.6
	(0.06)	(0 004)	
12-15	1.1	0.14	5.3
	(0.04)	(0.005)	
15-18	1.1	0.11	5.3
	(0.04)	(0.004)	
18-21	0.54	0.06	5.8
	(0.02)	(0.002)	
Microplot 2.			
0-3	20	0.77	17
	(0.72)	(0.02)	
3-6	18	0.58	13
	(0.67)	(0.02)	
6-9	35	1.2	30
	(1.3)	(0.04)	
9-12	22	0.79	13
	(0.83)	(0.02)	
12-15	7.6	0.37	25
	(0.28)	(0.01)	
15-18	2.7	0.18	7.9
	(0.10)	(0.006)	
18-21	2.4	0 16	6.0
	(0.09)	(0.005)	

[a]See Figs. 2 and 3 for Microplots location
[b]Concentration in Bq/g

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Appendix B (continued)

Soil Depth (cm)	^{241}Am pCi/g	^{137}Cs pCi/g	Gross α cpm
Microplot 3.			
0-3	26	1.2	20
	(0.95)	(0.04)	
3-6	11	0.41	13
	(0.40)	(0.01)	
6-9	5.7	0.16	10
	(0.21)	(0.005)	
9-12	3.0	0.10	7.2
	(0.11)	(0.003)	
12-15	1.1	0.12	6.5
	(0.04)	(0.004)	
15-18	0.54	0.00	5.5
	(0.02)	(0.0)	
18-21	0.54	0.03	4.1
	(0.02)	(0.001)	
Microplot 4.			
0-3	27	0.89	24
	(1.0)	(0.03)	
3-6	9.7	0.42	12
	(0.36)	(0.01)	
6-9	6.0	0.31	8.7
	(0.22)	(0.01)	
9-12	3.2	0.14	7.5
	(0.12)	(0.005)	
12-15	1.9	0.00	5.8
	(0.07)	(0.0)	
15-18	0.81	0.05	6.9
	(0.03)	(0.001)	
18-21	0.81	0.03	7.9
	(0.03)	(0.001)	

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Appendix B (continued)

Soil Depth (cm)	^{241}Am pCi/g	^{137}Cs pCi/g	Gross α cpm
Microplot 5.			
0-3	25	1.1	22
	(0.92)	(0.04)	
3-6	8.9	0.39	17
	(0.33)	(0 01)	
6-9	4.3	0.21	11
	(0.16)	(0.007)	
9-12	1.9	0.18	6.2
	(0.07)	(0.006)	
12-15	1.1	0.08	8.1
	(0.04)	(0.002)	
15-18	0.81	0.08	7.3
	(0.03)	(0.002)	
18-21	0.81	0.04	2.9
	(0.03)	(0.001)	
Microplot 6.			
0-3	30	1.1	24
	(1.1)	(0.04)	
3-6	15	0.67	13
	(0.57)	(0.02)	
6-9	5.7	0.19	7.4
	(0.21)	(0.007)	
9-12	3.0	0.08	7.2
	(0.11)	(0.002)	
12-15	1.1	0.04	6.4
	(0.04)	(0.001)	
15-18	0.81	0.00	6.3
	(0.03)	(0.0)	
18-21	0.27	0.04	6.7
	(0.01)	(0.001)	

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Soil Depth (cm)	^{241}Am pCi/g	^{137}Cs pCi/g	Gross α cpm
Microplot 7.			
0-3	22	1.2	19
	(0.81)	(0.04)	
3-6	12	0.69	14
	(0.44)	(0.02)	
6-9	3.0	0.17	6.2
	(0.11)	(0.006)	
9-12	1.4	0.10	5.4
	(0.05)	(0.003)	
12-15	0.54	0.01	5.0
	(0.02)	(0.0003)	
15-18	0.27	0.04	4.6
	(0.01)	(0.001)	
18-21	0.27	0.03	4.5
	(0.01)	(0.001)	
Microplot 8.			
0-3	38	1.0	29
	(1.4)	(0.03)	
3-6	21	0.51	23
	(0.76)	(0.01)	
6-9	6.8	0.22	16
	(0.25)	(0.008)	
9-12	5.1	0.05	8.0
	(0.19)	(0.001)	
12-15	2.2	0.09	6.4
	(0.08)	(0.003)	
15-18	1.6	0.12	8.4
	(0.06)	(0.004)	
18-21	0.81	0.06	5.6
	(0.03)	(0.002)	

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Appendix B (continued)

Soil Depth (cm)	^{241}Am pCi/g	^{137}Cs pCi/g	Gross α cpm
Microplot 9.			
0-3	41	1.5	26
	(1.5)	(0.05)	
3-6	30	1.3	26
	(1.1)	(0.04)	
6-9	12	0.48	18
	(0.46)	(0.01)	
9-12	4.9	0.19	8.0
	(0.18)	(0.007)	
12-15	3.5	0.11	8.4
	(0.13)	(0.004)	
15-18	3.8	0.10	10
	(0.14)	(0.003)	
18-21	1.6	0.08	6.7
	(0.06)	(0.002)	
Microplot 10.			
0-3	24	0.79	26
	(0.88)	0.02)	
3-6	23	0.74	23
	(0.86)	(0.02)	
6-9	14	0.31	15
	(0.50)	0.01)	
9-12	3.8	0.11	8.9
	(0.14)	(0.004)	
12-15	2.2	0.07	7.9
	(0.08)	(0.002)	
15-18	1.1	0.03	6.9
	(0.04)	(0.001)	
18-21	0.81	0.04	8.3
	(0.03)	0.001)	

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